Crop Sequence Effects on Response of Corn and Soil Inorganic Nitrogen to Fertilizer and Manure Nitrogen

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ABSTRACT

Fertilizer N and manure frequently are applied to corn (*Zea mays* L.) grown after alfalfa (*Medicago sativa* L.) at rates similar to those applied to continuous corn, although corn following alfalfa typically requires little additional N to attain maximum dry matter. Consequently, similar amounts of applied N may affect soil NO_3 differently in rotational than in continuous corn. There is little information evaluating crop sequence effects on residual soil NO_3 derived from fertilizer N and manure. In two 2-yr experiments at two locations in Minnesota, we evaluated the effect of crop sequence on response of corn grain dry matter, grain N, and stover N, and of soil inorganic N (NO_3–N and NH_4–N) to fertilizer N and dairy manure. Grain dry matter of first-year corn following alfalfa did not respond to applied N at Rosemount and typically was less responsive than continuous corn at Waseca. Crop sequence effects on soil NO_3 response to manure and fertilizer N were similar. Preplant fertilizer N application of 157 kg ha^{-1} increased residual soil NO_3–N the following spring an average of 45 kg ha^{-1} more in first-year corn following alfalfa than in continuous corn, except when excessive precipitation caused apparent high losses of applied N. Grain N content and soil NO_3 responded similarly to fertilizer N in both second-year corn following alfalfa and continuous corn. Efforts to reduce the build-up and potential loss of soil NO_3 in the corn portion of alfalfa–corn rotations should focus on reducing N application to first-year corn following alfalfa. These N applications have little agronomic value and can dramatically increase residual soil NO_3.

FIRST-YEAR CORN following alfalfa typically requires less fertilizer N than does continuous corn to attain maximum grain dry matter yield (Shrader et al., 1966; Higgs et al., 1976; Voss and Shrader, 1979; Baldock et al., 1981; Fox and Piekielek, 1988). In some cases there has been no grain dry matter response to fertilizer N in first-year corn following alfalfa (Schmid et al., 1959; Fox and Piekielek, 1988; Bundy and Andraski, 1993). Long-term studies in Wisconsin (Higgs et al., 1976) and Iowa (Voss and Shrader, 1979) showed occasional responses to fertilizer N up to 35 kg ha^{-1}. Corn grown the second year following plowdown of alfalfa required less fertilizer N than continuous corn, but more than first-year corn, to attain maximum grain dry matter in studies in Wisconsin (Higgs et al., 1976), Iowa (Voss and Shrader, 1979), and Pennsylvania (Fox and Piekielek, 1988).

Recent studies have documented that farmers regularly apply fertilizer N and/or manure to corn in alfalfa–corn rotations in excess of recommended rates (Daberkow et al., 1988; Legg et al., 1989; El-Hout and Blackmer, 1990). In the 10 major corn-producing states in 1987, the mean fertilizer N rate applied to corn grown in rotation was 140 kg ha^{-1}, compared with 154 kg ha^{-1} in continuous corn (Daberkow et al., 1988). In many of these states, a similar fertilizer N rate was applied to corn in rotation as to continuous corn.

There is limited information on N recovery by corn and N loss in corn–alfalfa rotations. Fox and Piekielek (1988) concluded that total N uptake response by corn to fertilizer N application is dependent on the previous crop (continuous corn vs. 3 yr of alfalfa), as shown by corn after alfalfa having a higher N content only at lower fertilizer N rates. In Wisconsin studies, fertilizer N increased grain N concentration in first-year corn following alfalfa, although there was no grain dry matter response to fertilizer N in 8 of 22 site-years (Bundy and Andraski, 1993). Soil inorganic N was monitored in first-year corn following alfalfa throughout a growing season in Ontario (Aflakpui et al., 1993). Fertilizer N did not increase grain dry matter, but caused a linear increase in soil NO_3 in the top 15 cm from July through the last sampling in August.

Similarly, overapplication of N as fertilizer or manure to continuous corn has been associated with excess NO_3 in the soil profile at the end of the growing season (Olsen et al., 1970; Kimble et al., 1972; Evans et al., 1977; Hahne et al., 1977; Russelle et al., 1981; Jokela and Randall, 1989; Jokela, 1992). Excess NO_3 can leach beyond the root zone over winter in humid and subhumid regions (Olsen et al., 1970; Kimble et al., 1972; Evans et al., 1977; Jokela and Randall, 1989). The lower N requirement of corn following alfalfa compared with continuous corn creates the potential for greater NO_3 losses when rates of applied N are not reduced.

Our objective was to determine the effects that fertilizer and manure N have on grain dry matter, grain and stover N uptake, and residual NO_3 in the soil profile in the fall and subsequent spring in corn following alfalfa compared with continuous corn.

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Published in Agron. J. 87:876–883 (1995).

Table 1. Agronomic and soil sampling data for experiments at Rosemount and Waseca, MN.

Location	Exp.	Year	Planting date	Harvest date	Corn population	Soil sampling dates		
						Initial	Fall	Spring
					plants ha^{-1}			
Rosemount	1	1990	3 May	29 Sept.	64 200	9 Apr. 1990	4 Nov. 1990	18 June 1991
		1991	21 May	25 Sept.	64 440	18 June 1991	13 Nov. 1991	4 June 1992
	2	1991	21 May	26 Sept.	64 220	16 Apr. 1991	16 Oct. 1991	15 June 1992
		1992	5 May	13 Oct.	64 440	15 June 1992	28 Oct. 1992	6 June 1993
Waseca	1	1990	29 May	2 Oct.	65 750	26 Apr. 1990	17 Oct. 1990	23 Apr. 1991
		1991	21 May	27 Sept.	67 900	23 Apr. 1991	24 Oct. 1991	2 June 1992
	2	1991	21 May	2 Oct.	67 930	17 Apr. 1991	5 Nov. 1991	1 June 1992
		1992	12 May	19 Oct.	58 300	1 June 1992	13 Nov. 1992	ND†

† ND, not determined (sampling not done).

MATERIALS AND METHODS

We conducted two 2-yr experiments on a Webster clay loam (fine-loamy, mixed, mesic Typic Hapludolls) at the Southern Experiment Station, Waseca, MN, and on a Tallula silt loam (coarse-silty, mixed, mesic Typic Hapludolls) at Agronomy Hill, Rosemount Agricultural Experiment Station, Rosemount, MN. Fertilizer N and dairy cow (*Bos taurus*) manure treatments were initiated in 1990 in Exp. 1 and in 1991 in Exp. 2.

Plot History

The entire plot area in Exp. 1 was seeded to 'Blazer' alfalfa in April 1984 at Waseca and to Pioneer[1] '532' alfalfa in fall 1985 at Rosemount. Portions of each area were moldboard plowed in spring 1988 to establish the corn portion of an alfalfa–corn rotation, creating a randomized complete block design with two treatments (corn and alfalfa), with four blocks at Waseca and three blocks at Rosemount. Alfalfa continued to be managed for hay production in a three-cut system, while corn was managed for grain production in 1988 and 1989. Corn plots at both locations received recommended N rates both years prior to initiation of fertilizer and manure treatments, and primary tillage was by chisel plow in 1989.

In Exp. 2, corn and alfalfa were established in spring 1988 in a randomized complete block design with four blocks at Waseca and three blocks at Rosemount. Inoculated 'DK120' alfalfa was seeded at a rate of 14.6 kg ha^{-1}. At Rosemount, the alfalfa stand received 130 mm irrigation water in 1988 and was reseeded in spring 1990 with a no-till drill to fill open patches in the stand after significant winter kill during 1989–1990. Alfalfa was harvested once in 1988 and then managed as a three-cut system in 1989 and 1990 at both locations. Corn was managed for grain production as in Exp. 1, except that primary tillage was by moldboard plow at Rosemount.

Experimental Methods

At Rosemount in Exp. 1, alfalfa stands were moldboard plowed 23 Apr. 1990 before establishing fertilizer N treatments. The stand was in poor condition (estimated to be 25% alfalfa), with large grassy areas. Alfalfa stands in Exp. 2 averaged 21 alfalfa plants m^{-2} when moldboard plowed 24 Apr. 1991. At Waseca in Exp. 1, the stand averaged 32 alfalfa plants m^{-2} when moldboard plowed 26 Apr. 1990. In Exp. 2, a good stand of alfalfa (plant population not determined) was chisel plowed 31 Oct. 1990 in preparation for subsequent spring fertilizer N treatments. In all cases, adjacent corn plots received similar primary tillage. Plots were moldboard plowed in spring at Rosemount and in fall at Waseca in the second year of both experiments.

Agronomic information on plant population and dates of planting, harvesting, and soil sampling are presented in Table 1. In the first year of N treatments in both experiments, five fertilizer N rates as urea and three dairy cow manure rates were broadcast-applied to random subplots within each previous crop main plot. Subplots were 3.0 by 9.0 m (four rows wide) for fertilizer N treatments and 4.6 by 9.0 m (six rows wide) for manure treatments. Fertilizer N rates for continuous corn were 0, 67, 112, 157, and 202 kg N ha^{-1}; rates for first-year corn following alfalfa were 0, 34, 67, 112, and 157 kg N ha^{-1}. Manure composition and rates applied to continuous corn and first-year corn following alfalfa are reported in Tables 2 and 3. In all but Exp. 2 at Waseca, manure was applied immediately before spring plowdown of alfalfa and was incorporated within 1 h of application. At Waseca in Exp. 2, manure was applied 14 Apr. 1991 to the plots plowed the previous fall and was incorporated by disking within 1 h. In all experiments, five subplots in each previous crop main plot were reserved to determine N response in second-year corn; these plots received 112 kg fertilizer N ha^{-1} if the previous crop was corn or no fertilizer N if the previous crop was alfalfa. This ensured that all fertilizer N treatments within a crop sequence had the same fertilization history in the second phase of the experiment. After fertilizer N application, the entire experimental area was disked and planted to Pioneer hybrid 3751 corn.

In the second experimental year, five fertilizer N rates as urea were broadcast-applied to random subplots that had received uniform fertilizer N treatments the previous year. In Exp. 1, both cropping sequences received 0, 67, 112, 157, and 202 kg N ha^{-1}. In Exp. 2, second-year treatments in continuous corn were 0, 67, 112, 157, and 202 kg N ha^{-1}, whereas treatments in second-year corn following alfalfa were 0, 34, 67, 112, and 157 kg N ha^{-1}. All fertilizer N was applied preplant as urea and disk incorporated. No manure was applied to the second phase of the experiment.

[1] Names are necessary to report factually on available data; however, the USDA and the Univ. of Minnesota neither guarantee nor warrant the standard of the product, and the use of the name implies no approval of the product to the exclusion of others that may also be suitable.

Table 2. Nutrient content of dairy manure applied at Rosemount and Waseca, MN.

Location	Year applied	Dry matter	pH	Total NH_4-N	N	P	K	S	Na
		%		kg m^{-3}					
Rosemount	1990	10.4	ND†	1.43	4.36	0.91	3.13	0.71	0.09
	1991	11.7	5.7	2.44	5.00	0.77	3.42	0.34	0.17
Waseca	1990	10.1	6.1	1.61	3.85	0.74	3.30	0.34	0.60
	1991	8.7	7.4	2.05	4.26	0.97	4.72	0.25	7.26

† ND, not determined.

Table 3. Quantity of dairy manure applied and two indicators of manure N availability at Rosemount and Waseca, MN.

Location	Year applied	Quantity applied	Total applied N	Predicted available N†
		m^3 ha^{-1}	kg ha^{-1}	
Rosemount	1990‡	28.0	120	70
		46.7	200	110
		65.4	290	150
		103.0	450	240
	1991	31.1	160	100
		62.2	310	200
		93.3	470	300
Waseca	1990‡	28.0	110	60
		46.7	180	110
		65.4	250	150
		102.7	400	230
	1991	28.0	120	80
		56.0	240	130
		93.4	400	250

† Assuming 100% of NH_4-N and 30% of organic N was available for crop uptake the year of application.
‡ 28.0, 46.7, and 65.4 m^3 ha^{-1} were applied to first-year corn following alfalfa, and 28.0, 65.4, and 103 m^3 ha^{-1} were applied to continuous corn at both locations in 1990.

Weed control was excellent with a combination of preemergence herbicides and one mechanical cultivation. Rootworm control was accomplished with recommended insecticides. After obtaining grain and stover samples for analysis in the fall, the remaining plot area was harvested for grain by combine each year.

Sample Acquisition and Analysis

Corn plant population was determined on 12.2 m of row within 10 d of physiological maturity. Ears were harvested from 12.2 m of row, weighed, and a subsample of 10 ears was retained. At the same time, stover was harvested from 6.1 m of row, weighed, and a subsample of six plants was retained. Grain and stover subsamples were dried in forced-air ovens at 60°C to a constant mass to determine water content. Ears were shelled, the grain weighed, and cobs discarded. A subsample of dry grain was ground to a uniform fine texture in a Stein mill (Fred Stein Laboratories, Atchison, KS). Stover was ground in a Wiley mill (Arthur H. Thomas Co., Philadelphia, PA) to pass a 1-mm screen. Subsamples of grain and stover were digested using the salicylic acid modification of the Kjeldahl method to include NO_2^- and NO_3^- (Bremner and Mulvaney, 1982), and N concentration was determined on a Wescan Model 360 ammonia analyzer (Alltech Assoc., Deerfield, IL).

Soil samples were obtained with a 3.8-cm-diam., truck-mounted hydraulic probe. Two cores from each plot, one centered over a row and one centered between rows, were taken to a depth of 2.4 m at Rosemount and to 1.5 m (when possible) at Waseca. The two cores from a plot were divided into 30-cm increments, composited by depth, and subsampled for analysis. Subsamples were dried at 35 to 40°C in forced-air dryers and pulverized before analysis. Three-gram subsamples were extracted with 30 mL of 2 mol L^{-1} KCl by shaking for 60 min. and centrifugation at 2000 *g* for 10 min. The extracts were analyzed for total inorganic N and NH_4^+ concentration on a Wescan ammonia analyzer (NO_3^- determined by difference) or for NH_4^+ and NO_3^- concentration on an Alpkem rapid flow analyzer (Alpkem Corp., Clackamas, OR).

Statistical Analysis

Effects of previous crop, year, and location on initial soil NO_3 and NH_4 content before application of fertilizer or manure N were tested using the Generalized Linear Models procedure (SAS Inst., 1987).

Fertilizer N response of all yield and soil parameters was modeled separately from manure N response. Regression analysis techniques using the quadratic polynomial were used to test hypotheses that regression lines from different cropping sequences or different experiments (years) had the same slope (Weisberg, 1985; Weisberg and Cook, 1990). A general model (i.e., each rotation phase in each experiment had unique intercept and slope coefficients) was compared with more restrictive models (i.e., some or all rotation phases and experiments had the same slope coefficients but unique intercepts). Restrictions to the model were rejected if they significantly increased error sums of squares (α = 0.05) (Weisberg and Cook, 1990). Regression lines of the location models were compared across locations using the same restriction test. Nonsignificant quadratic and linear coefficients were removed stepwise from the overall model (α = 0.10). Finally, restrictions were applied to test for effects of crop sequence, year, and location on intercept coefficients (α = 0.05). As an indicator of model fit, the appropriate intercept values were subtracted from the dependent variable and r^2 was determined for the intercept adjusted model.

Paired *t*-tests were used to evaluate grain dry matter and grain N at the maximum rate of N applied as manure and fertilizer N rate within each crop sequence.

Calculations

Apparent soil-derived NO_3 was estimated using the *y*-intercept of the response of soil NO_3–N to applied N. This estimate includes soil NO_3 derived from the plowdown of alfalfa. Crop sequence effects on soil-derived NO_3 were calculated as the difference between *y*-intercepts for corn following alfalfa and continuous corn. Apparent fertilizer- or manure-derived soil NO_3 was calculated from slope coefficients describing increased soil NO_3–N in response to applied N. This estimate of fertilizer- or manure-derived soil NO_3 assumes that there was no effect of applied N on soil-derived NO_3.

Plant availability of N from the manure was estimated two ways. First, available N was estimated assuming that 100% of the NH_4–N and 30% of the organic N was available to corn the first growing season after application (Sutton et al., 1985). This estimate was used for the *x*-axis when plotting plant yield parameters and soil NO_3–N, and is reported for each manure rate in Table 3. Second, agronomically equivalent manure and fertilizer N rates were determined by the traditional N credit method; that is, the corn grain yield attained with a given rate of manure was located along the curve of continuous corn yield response to fertilizer N to estimate the equivalent quantity of fertilizer N.

RESULTS

Weather

Drier and warmer than normal conditions in 1988 and 1989 preceded this experiment. Precipitation was above average during the 3 yr of the experiment (Fig. 1). Precipitation in 1991 was exceptionally high at both locations (249 and 486 mm above average at Rosemount and Waseca, respectively) and contributed to a wet spring in 1992. Mean summer temperatures were 0.4 and 1.2°C above normal in 1990 and 1991 at Rosemount and Waseca, respectively. Summer temperatures averaged 2.7 and 2.3°C below the long-term mean in 1992 at Rosemount and Waseca, respectively.

Plant Response to Applied Nitrogen

First-Year Corn following Alfalfa vs. Continuous Corn

In all comparisons with no fertilizer N applied, corn following alfalfa had greater grain dry matter, grain N content, and stover N content than continuous corn. Previous

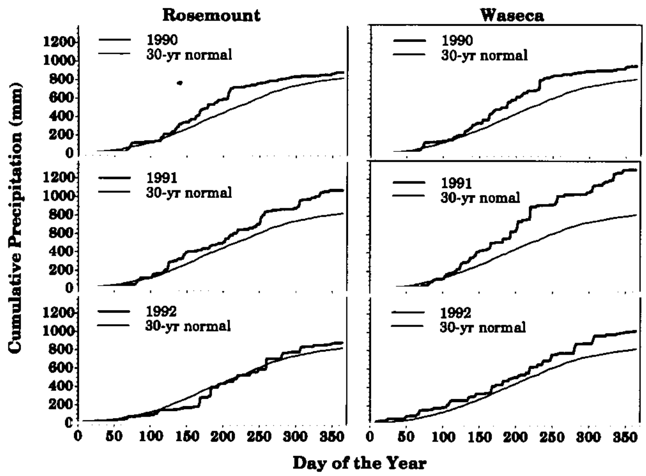

Fig. 1. Cumulative precipitation in 1990, 1991, and 1992, and the 30-yr mean (1961–1990) at Rosemount and Waseca, MN.

crop affected the response of grain dry matter and grain N content to fertilizer N as shown by the slope coefficients (Fig. 2). In contrast, stover N content response was not affected by previous crop.

Location affected fertilizer N response of grain dry matter, grain N, and stover N (Fig. 2). At Rosemount, grain dry matter in first-year corn following alfalfa did not respond to fertilizer N, whereas continuous corn grain dry matter yield increased by 2.2 Mg ha^{-1} with 202 kg ha^{-1} fertilizer N (the highest fertilizer N rate applied to continuous corn) in both 1990 and 1991 (Fig. 2). Grain N concentration following alfalfa at Rosemount was less responsive to fertilizer N than was continuous corn (data not shown); N concentration at the intercept (0 N) was greater following alfalfa (14.1 vs. 12.1 g kg^{-1}). Maximum grain N yield was attained with 125 kg ha^{-1} fertilizer N in first-year corn following alfalfa, whereas response was linear in continuous corn both years (Fig. 2). Application of 157 kg ha^{-1} fertilizer N (maximum rate applied to first-year corn following alfalfa) increased grain N yield 53 kg N ha^{-1} in continuous corn vs. 22 kg N ha^{-1} in first-year corn following alfalfa, compared with nonfertilized corn.

At Waseca, grain dry matter in both cropping sequences responded to fertilizer N, although increases were larger in continuous corn (Fig. 2). Maximum grain dry matter was attained with 58 kg ha^{-1} fertilizer N in first-year corn following alfalfa in 1990, resulting in a 0.3 Mg ha^{-1} increase in grain dry matter, in contrast to a 1.9 Mg ha^{-1} increase in continuous corn grain dry matter with 202 kg ha^{-1} fertilizer N. Response to fertilizer N was linear in both crop sequences in 1991; application of 157 kg ha^{-1} fertilizer N (maximum rate applied to first-year corn following alfalfa) resulted in a 1.5 Mg ha^{-1} increase in grain dry matter yield in first-year corn following alfalfa vs. a 3.2 Mg ha^{-1} increase in continuous corn, compared with nonfertilized corn.

Grain N concentration response to fertilizer N at Waseca was not influenced by crop sequence (data not shown), although first-year corn following alfalfa contained about 1.7 g kg^{-1} more N at the 0 N rate than continuous corn. Maximum grain N yield was attained with 92 kg ha^{-1} fertilizer N in first-year corn following alfalfa in 1990, whereas grain N increased linearly in first-year corn following alfalfa in 1991 and in continuous corn both years (Fig. 2). Application of 157 kg ha^{-1} fertilizer N increased grain N yield an average of 23 kg ha^{-1} more in continuous corn than in first-year corn following alfalfa at Waseca.

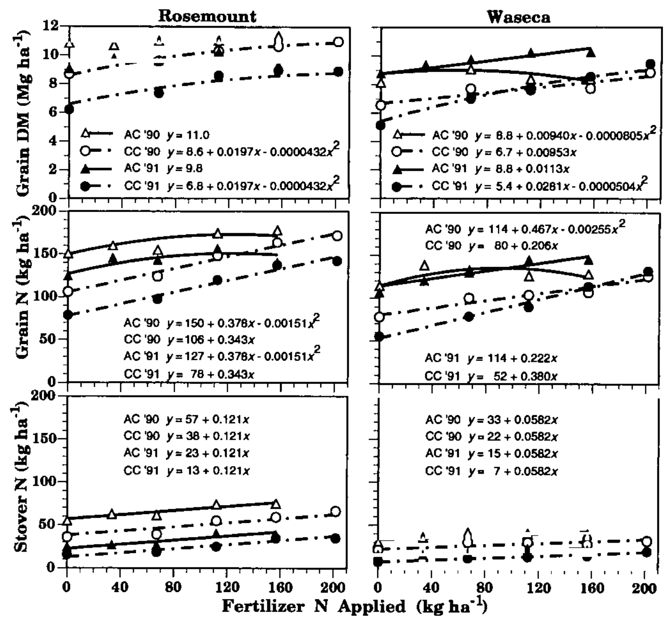

Fig. 2. Grain dry matter, grain N, and stover N response to fertilizer N in first-year corn following alfalfa (AC) and continuous corn (CC) at Rosemount and Waseca, MN. Data points are the mean of three replicates at Rosemount and four replicates at Waseca. Adjusted r^2 values for the model were 0.71, 0.75, and 0.57 for grain dry matter, grain N, and stover N, respectively.

Crop sequence effects on corn response to manure N and fertilizer N were similar. At Rosemount, the primary effect of N source was that N response to manure was always linear (Fig. 3), whereas in some cases response to fertilizer N was quadratic (Fig. 2). This may be due in part to the greater variability associated with yield response to manure, thereby masking what may in fact have been a quadratic response.

At Waseca, N source (manure vs. fertilizer N) interacted with crop sequence effects on yield on two occasions. In the first, crop sequence did not affect plant response to manure in 1990, in contrast to results with fertilizer N (compare Fig. 2 and 3). In the second, grain dry matter and grain N yield increased in response to fertilizer N but not to manure in first-year corn following alfalfa in 1991.

Second-Year Corn following Alfalfa vs. Continuous Corn

At Rosemount, there was no effect of previous crop on fertilizer N response of any plant parameter except stover N yield in 1991 (Fig. 4). The intercept value (0 kg N ha^{-1}) for second-year corn following alfalfa was higher than for continuous corn in grain and stover N yield in 1991 and grain dry matter in 1992 (Fig. 4).

At Waseca, less fertilizer N was required to attain maximum grain dry matter in second-year corn following alfalfa than in continuous corn, and the reduction interacted with year (Fig. 4). Crop sequence did not affect grain N yield response to fertilizer N both years and stover N yield response in 1991. Second-year corn following alfalfa had higher intercept values than continuous corn for all measured plant parameters except stover N.

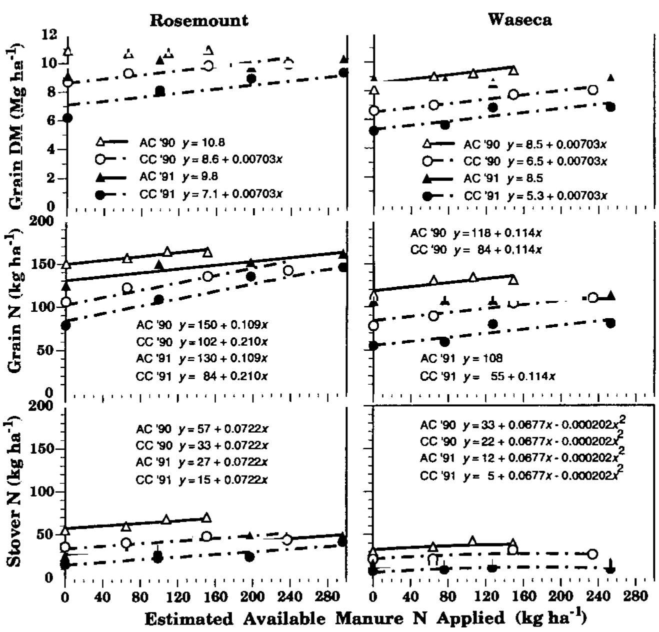

Fig. 3. Grain dry matter, grain N, and stover N response to manure in first-year corn following alfalfa (AC) and continuous corn (CC) at Rosemount and Waseca, MN. Available manure N was estimated based on 100% of NH_4-N and 30% of organic N being available for crop uptake the year of application. Data points are the mean of three replicates at Rosemount and four replicates at Waseca. Adjusted r^2 values for the model were 0.46, 0.63, and 0.44 for grain dry matter, grain N, and stover N, respectively.

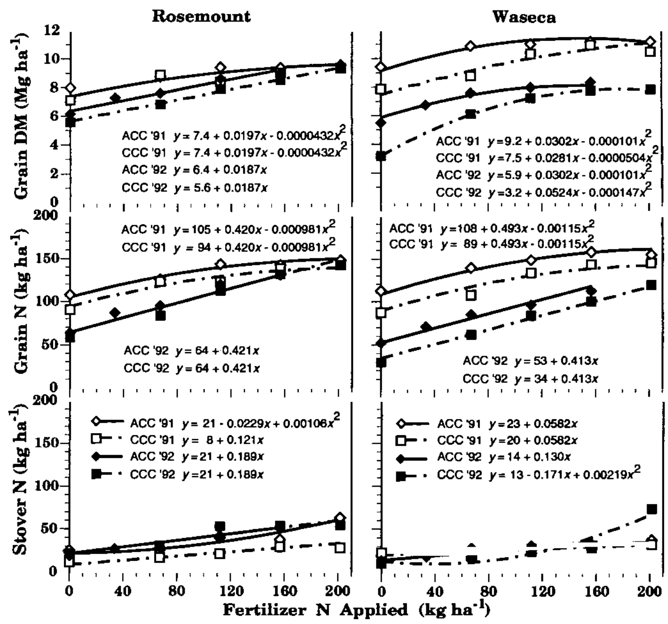

Fig. 4. Grain dry matter, grain N, and stover N response to fertilizer N in second-year corn following alfalfa (AC) and continuous corn (CC) at Rosemount and Waseca, MN. Data points are the mean of three replicates at Rosemount and four replicates at Waseca. Adjusted r^2 values for the model were 0.77, 0.80, and 0.72 for grain dry matter, grain N, and stover N, respectively.

Soil Inorganic Nitrogen Response to Applied Nitrogen

Before initiating fertilizer N and manure treatments, significant differences in soil NO_3 in the surface 1.5 m due to previous crop existed in 1990 but not in 1991 (data not shown). Nitrate in continuous corn exceeded that in alfalfa by 40 kg N ha^{-1} at Rosemount and by 100 kg N ha^{-1} at Waseca in spring 1990. Crop sequence effects on soil NO_3 with no fertilizer N applied still were apparent at the fall sampling in all site years, but had disappeared by the subsequent spring sampling (1 yr after initiation of the experiment) in three of four site years (intercept values, Fig. 5 and 6). First-year corn following alfalfa with no fertilizer N applied averaged 16 kg ha^{-1} more NO_3-N in the top 0.6 m in the fall than in continuous corn, but there was no effect of crop sequence at any depth the following spring at Rosemount (Fig. 5). At Waseca (Fig. 6), first-year corn following alfalfa had 35 kg ha^{-1} more soil NO_3-N in fall 1990 than continuous corn, whereas continuous corn exceeded first-year corn following alfalfa by 15 kg ha^{-1} in fall 1991.

Crop sequence, season (fall vs. the following spring), year, and location all influenced the effect of spring-applied N on soil NO_3 (slope coefficients, Fig. 5–8). At Rosemount, crop sequence affected soil NO_3 response to fertilizer N only at the spring samplings (1 yr after fertilizer application) (Fig. 5). When both received 157 kg ha^{-1} fertilizer N, first-year corn following alfalfa had 54 kg ha^{-1} more fertilizer-derived soil NO_3-N in the 0.6- to 1.5-m increment in June 1991 and 35 kg ha^{-1} more fertilizer-derived soil NO_3-N in the 1.5- to 2.4-m increment in June 1992 compared with continuous corn. This was due to an increase in fertilizer-derived NO_3 between the fall and spring samplings in first-corn following alfalfa in both experiments, and concurrent over-winter losses in continuous corn in Exp. 1 (compare fall and subsequent spring slope coefficients, Fig. 5). Soil NO_3 response to spring-applied manure was influenced by crop sequence in fall and the following spring (1 yr after manure application) in the 1990 experiment, and spring only (1 yr after manure application) in the 1991 experiment (Fig. 7).

At Waseca, crop sequence influenced soil NO_3 response to N applied in spring 1990 but not spring 1991 (slope coefficients, Fig. 6 and 8). Application of fertilizer and manure N in spring 1990 increased soil NO_3 more in first-year corn following alfalfa than in continuous corn in both fall 1990 and the subsequent spring. Compared with continuous corn, first-year corn following alfalfa had 51 kg ha^{-1} more fertilizer-derived soil NO_3-N in the fall 1990 sampling and 88 kg ha^{-1} more the following spring (1991) after 157 kg ha^{-1} fertilizer N was applied in spring 1990. The difference between the two crop sequences increased over winter primarily because fertilizer-derived soil NO_3 decreased in continuous corn.

There was evidence of downward movement of fertilizer derived NO_3 in the soil profile between the fall and subsequent spring in both crop sequences at Rosemount. The quantity of fertilizer-derived soil NO_3 in the 0.6- to 1.5-m increment increased between the fall and following spring sampling in both crop sequences in the 1990 experiment (Fig. 5). In the 1991 experiment, the effect of fertilizer N was limited to the top 1.5 m in fall, but extended to the 1.5- to 2.4-m increment the following spring in both crop sequences (Fig. 5). Greater depth of NO_3 leaching in the 1991 experiment was associated with 125 mm more precipitation after grain harvest in fall 1991 than in fall 1990 (Fig. 1).

It was more difficult to identify downward movement

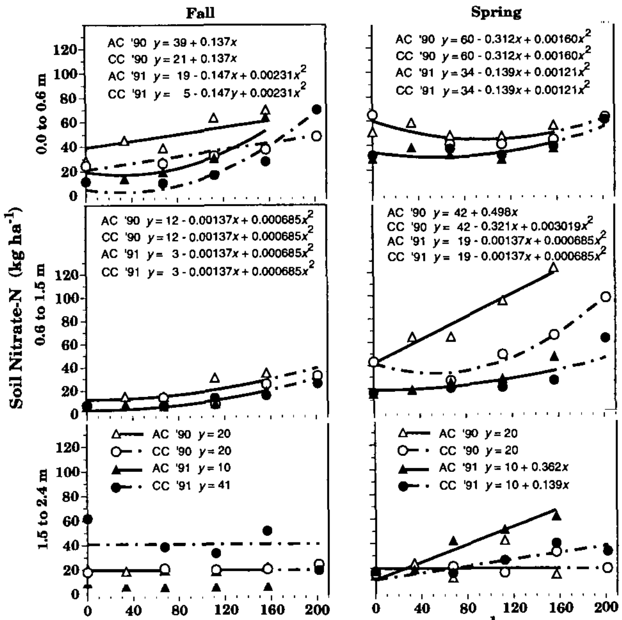

Fig. 5. Soil NO_3-N as affected by spring-applied fertilizer N in first-year corn following alfalfa (AC) and continuous corn (CC) in fall and following spring (one year after application) at Rosemount, MN. Data points are the mean of three replicates. Adjusted r^2 values for the model were 0.52, 0.63, and 0.31 for the 0.0- to 0.6-m, 0.6- to 1.5-m, and 1.5- to 2.4-m depth increments, respectively.

of NO_3 in the soil profile at Waseca. In 1990, there was no net loss of fertilizer-derived soil NO_3 in corn following alfalfa between the fall and spring samplings (over winter), whereas in continuous corn all fertilizer-derived soil NO_3 was lost over winter (Fig. 6). In 1991, all fertilizer-derived soil NO_3 was lost over winter from both crop sequences. Nitrate losses in continuous corn in 1990 could be attributed to leaching losses and/or gaseous losses via denitrification. Limited fertilizer-derived soil NO_3 in the soil profile in the fall of the 1991 experiment and no fertilizer-derived soil NO_3 the following spring (1 yr after fertilizer application) was probably due to the exceptionally high rainfall amounts at Waseca (Fig. 1).

Soil NH_4 content was not affected by spring-applied N in either fall or spring at either location (data not shown).

Crop sequence had no effect on soil NO_3 response to fertilizer N when comparing second-year corn following alfalfa and continuous corn in either fall and spring at either location (data not shown).

DISCUSSION

Results at Rosemount confirm the limited responsiveness of grain dry matter yield to fertilizer N for first-year corn following alfalfa observed on this and other silt loam soils in the Upper Midwest (Schmid et al., 1959; Higgs et al., 1976; Voss and Shrader, 1979; Bundy and Andraski, 1993). First-year corn following alfalfa at Waseca responded to higher fertilizer N rates than at Rosemount in agreement with long-term studies in Iowa on similar soils (Voss and Shrader, 1979, 1984). Also in agreement with our results, Hesterman et al. (1986) found that first-year corn grain dry matter yield following plowdown of a 1-yr-old stand of alfalfa responded to up to 170 kg ha^{-1}

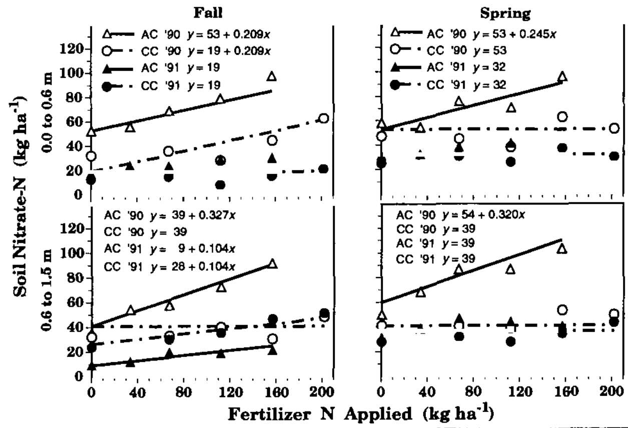

Fig. 6. Soil NO_3-N as affected by spring-applied fertilizer N in first-year corn following alfalfa (AC) and continuous corn (CC) in fall and following spring (one year after application) at Waseca, MN. Data points are the mean of four replicates. Adjusted r^2 values for the model were 0.29 and 0.43 for the 0.0- to 0.6-m and 0.6- to 1.5-m depth increments, respectively.

fertilizer N at Waseca. High rainfall (Fig. 1) contributed to low fertilizer N use efficiency at Waseca. In 1990, there was 135 mm of precipitation in the 25 d after fertilizer N application and in 1991 rainfall was excessive throughout the growing season.

The lack of interaction between corn yield response to fertilizer N and crop sequence when comparing second-year corn following alfalfa vs. continuous corn at Rosemount has not been observed in other studies. Voss and Shrader (1984) attained maximum grain dry matter with similar amounts of N in second-year corn following alfalfa and continuous corn in the data from 1971 to 1978,

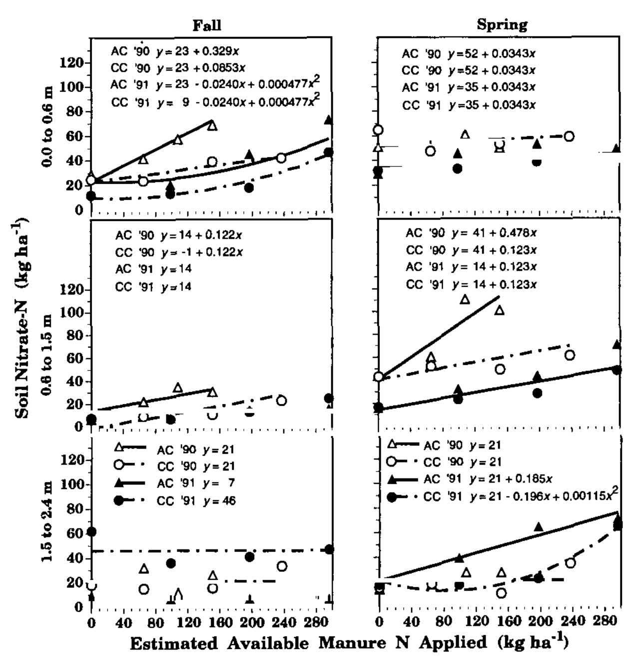

Fig. 7. Soil NO_3-N as affected by spring-applied manure in first-year corn following alfalfa (AC) and continuous corn (CC) in fall and following spring (one year after application) at Rosemount, MN. Available manure N was estimated based on 100% of NH_4-N and 30% of organic N being available for crop uptake the year of application. Data points are the mean of three replicates. Adjusted r^2 values for the model were 0.46, 0.47, and 0.41 for the 0.0- to 0.6-m, 0.6- to 1.5-m, and 1.5- to 2.4-m depth increments, respectively.

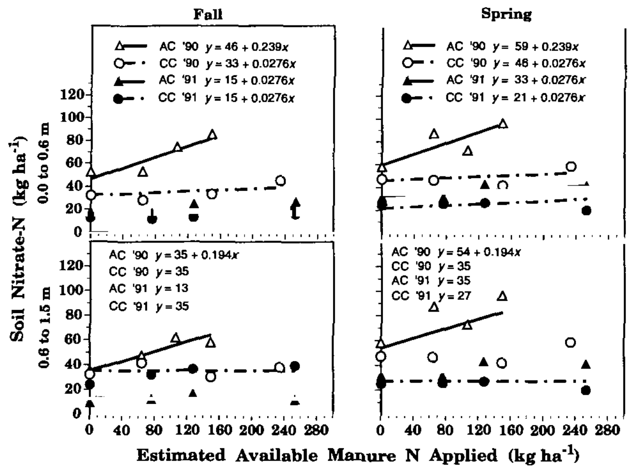

Fig. 8. Soil NO_3-N as affected by spring-applied manure in first-year corn following alfalfa (AC) and continuous corn (CC) in fall and following spring (one year after application) at Waseca, MN. Available manure N was estimated based on 100% of NH_4-N and 30% of organic N being available for crop uptake the year of application. Data points are the mean of four replicates. Adjusted r^2 values for the model were 0.30 and 0.31 for the 0.0- to 0.6-m and 0.6- to 1.5-m depth increments, respectively.

but they also observed an interaction between fertilizer N response and crop sequence. Our results on the silt loam soils at Rosemount suggest that second-year corn following alfalfa should be fertilized the same as continuous corn, because yield and residual soil NO_3 responded similarly to applied fertilizer N. Second-year corn following alfalfa at Waseca required similar fertilizer N to attain maximum yield as reported for 1979 to 1981 by Voss and Shrader (1984) on a similar soil in Iowa, but more fertilizer N than reported in earlier studies (Voss and Shrader, 1979).

We expected that fertilizer-derived soil NO_3 would be dependent on crop sequence but were surprised that the effect was greater in spring, 1 yr after application of N, than in the previous fall in three of four site-years. There are a number of scenarios that could explain this over-winter effect. We don't have enough information to definitively determine the contributing mechanism or mechanisms, but we can evaluate three possibilities in part. The over-winter increase in fertilizer-derived soil NO_3 was not from nitrification of fertilizer N present in the NH_4 form during the fall, because there was no effect of fertilizer N on exchangeable NH_4 in the soil. Differences between crop sequences in fertilizer-derived soil NO_3 also were not due to differential fertilizer N accumulation in the stover (as total N or NO_3) and its subsequent release to the soil. Crop sequence did not affect fertilizer N accumulation in the stover as total N (Fig. 3), and stover NO_3 content was not affected by crop sequence at Rosemount and was less than 2 kg ha^{-1} at Waseca (data not shown). One contributing factor to the over-winter effect could be net mineralization of N from corn residues in the crop sequence including alfalfa vs. net immobilization in the continuous corn system, because stover (and presumably roots) of corn following alfalfa had a higher N concentration than that of continuous corn.

Substantial amounts of fertilizer N were unaccounted for in the pools of N we monitored. Recovery of N in aboveground corn plants and as inorganic N in the soil from an application of 157 kg ha^{-1} fertilizer N ranged from 50 to 80% at Rosemount and 30 to 70% at Waseca. The N unaccounted for probably was contained in the roots, immobilized in soil organic matter, or lost from the sampled root zone via leaching and/or gaseous losses.

The highest manure rate applied to first-year corn following alfalfa had agronomically based N credits of 84 and 196 kg ha^{-1} fertilizer N at Rosemount in 1990 and 1991, respectively, and 115 and 74 kg ha^{-1} fertilizer N at Waseca in 1990 and 1991, respectively. All of these N credits were less than predicted N availability (Table 3).

Manure increased residual NO_3 in soil more than application of an agronomically equivalent amount of fertilizer N in both crop sequences at Rosemount in 1990 (51 kg NO_3-N ha^{-1} more in first-year corn following alfalfa and 14 kg NO_3-N ha^{-1} more in continuous corn), whereas fertilizer N had a larger effect in both crop sequences in 1991 (51 kg NO_3-N ha^{-1} more than manure). At Waseca in 1990, application of agronomically equivalent amounts of manure and fertilizer N had similar effects on residual N in the soil in first-year corn following alfalfa, whereas continuous corn had 20 kg ha^{-1} more residual NO_3-N from fertilizer N than manure. High rainfall in 1991 reduced residual NO_3 and crop sequence effects at Waseca.

There are few examples comparing agronomically equivalent quantities of fertilizer N and manure N on residual soil NO_3. Agronomically equivalent rates of manure and fertilizer N resulted in similar or slightly less residual NO_3 from manure in a 3-yr study in Vermont (Jokela, 1992). In other studies where the agronomic equivalence of the quantity of N being applied was less clear, there are examples of manure causing both more residual NO_3 (e.g., Miller and MacKenzie, 1978) and less residual NO_3 (e.g., Kimble et al., 1972). Our results demonstrate that residual NO_3 from manure and fertilizer N can be affected by year, crop sequence, and perhaps location. Year effects may be due in part to rainfall differences. Fertilizer N caused greater accumulation of residual N than manure N in the wetter year at Rosemount (1991). It has been hypothesized that NO_3 from manure may be more prone to denitrification, a process that would be promoted by above-average rainfall (Kimble et al., 1972).

SUMMARY AND CONCLUSIONS

In first-year corn following alfalfa at Rosemount, N (as fertilizer N or manure) had no effect on grain dry matter yield, and the N requirement for maximum grain N content was reduced compared with continuous corn. At Waseca, results were more variable between cropping sequences. Fertilizer N increased grain dry matter and N yield in both crop sequences but yield response was less in first-year corn following alfalfa. Crop response to manure was affected by crop sequence in the second but not the first experiment.

There was a greater increase in soil NO_3 associated with reduced plant accumulation of applied N in first-year corn following alfalfa at Rosemount, although the effect of crop sequence on soil NO_3 accumulation was not evident until the following spring. Application of 157 kg ha^{-1} fertilizer N increased soil NO_3-N by 45 kg ha^{-1} more in first-year corn following alfalfa than continuous corn. In one year, accumulated NO_3 was apparently leached below the corn root zone in both crop sequences. In both years, most accumulated soil NO_3 was below 0.6 m by the next spring, 1 yr after N application. At Waseca, soil NO_3 also was affected more by applied N in first-year corn following alfalfa than continuous corn in the first experiment. Application of 157 kg ha^{-1} fertilizer N increased soil NO_3 in the top 1.5 m of soil by 88 kg N ha^{-1} in first-year corn following alfalfa 1 yr after application, whereas it had no effect on soil NO_3 in continuous corn. In the second experiment, there was little effect of applied N on soil NO_3 in the fall and none the following spring in either crop sequence because of high precipitation.

Manure provided substantially less available N to corn than predicted using the availability index developed by Sutton et al. (1985). At both experimental locations, patterns of NO_3 distribution in the soil profile typically were similar for both N sources. The relative impact from application of agronomically equivalent amounts of N as manure and fertilizer N on soil NO_3 was dependent on year, crop sequence, and location.

Second-year corn following alfalfa and continuous corn responded similarly to fertilizer N at Rosemount, whereas second-year corn following alfalfa required less fertilizer N than continuous corn to attain maximum yield at Waseca. Crop sequence had no effect on soil NO_3 response to fertilizer N at either location when comparing second-year corn following alfalfa and continuous corn.

This research emphasizes the importance of reducing N applications to first-year corn following alfalfa. The limited agronomic value of N (both fertilizer and manure) on first-year corn following alfalfa already is reflected in most state fertilizer N recommendations. Our results demonstrate the sensitivity of soil NO_3 to both fertilizer and manure N applications to first-year corn following alfalfa compared with continuous corn.

REFERENCES

Aflakpui, G.K.S., T.J. Vyn, M.R. Hall, G.W. Anderson, and C.J. Swanton. 1993. Effect of tillage on nitrogen response in corn after established alfalfa. Can. J. Plant Sci. 73:73–81.

Baldock, B.O., R.L. Higgs, W.H. Paulson, J.A. Jackobs, and W.D. Shrader. 1981. Legume and mineral fertilizer effects on crop yields in several crop sequences in the Upper Mississippi Valley. Agron. J. 73:885–890.

Bremner, J.M., and C.S. Mulvaney. 1982. Nitrogen: Total. p. 592–622. *In* A.L. Page et al. (ed.) Methods of soil analysis. Part 2. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Bundy, L.G., and T.W. Andraski. 1993. Soil and plant nitrogen availability tests for corn following alfalfa. J. Prod. Agric. 6:200–206.

Daberkow, S., L. Hansen, and H. Vroomen. 1988. Low input practices. p. 22–25. Agricultural Outlook 148. USDA Econ. Res. Serv., Washington, DC.

El-Hout, N.M., and A.M. Blackmer. 1990. Nitrogen status of corn after alfalfa in 29 Iowa corn fields. J. Soil Water Conserv. 45:115–117.

Evans, S.D., P.R. Goodrich, R.C. Munter, and R.E. Smith. 1977. Effects of solid and liquid beef manure and liquid hog manure on soil characteristics and on growth, yield, and composition of corn. J. Environ. Qual. 6:361–368.

Fox, R.H., and W.P. Piekielek. 1988. Fertilizer N equivalence of alfalfa, birdsfoot trefoil, and red clover for succeeding corn crops. J. Prod. Agric. 1:313–317.

Hahne, H.C.H., W. Kroontje, and J.A. Lutz, Jr. 1977. Nitrogen fertilization: I. Nitrate accumulation and losses under continuous corn cropping. Soil Sci. Soc. Am. J. 41:562–567.

Hesterman, O.B., C.C. Sheaffer, D.K. Barnes, W.E. Lueschen, and J.H. Ford. 1986. Alfalfa dry matter and nitrogen production, and fertilizer nitrogen response in legume–corn rotations. Agron. J. 78:19–23.

Higgs, R.L., W.H. Paulson, J.W. Pendleton, A.E. Peterson, J.A. Jackobs, and W.D. Higgs. 1976. Crop rotation and nitrogen. Wisc. Agric. Exp. Stn. Bull. R2761.

Jokela, W.E. 1992. Nitrogen fertilizer and dairy manure effects on corn yield and soil nitrate. Soil Sci. Soc. Am. J. 56:148–154.

Jokela, W.E., and G.W. Randall. 1989. Corn yield and residual soil nitrate as affected by time and rate of nitrogen application. Agron. J. 81:720–726.

Kimble, J.M., R.J. Bartlett, J.L. McIntosh, and K.E. Varney. 1972. Fate of nitrate from manure and inorganic nitrogen in a clay soil cropped to continuous corn. J. Environ. Qual. 1:413–415.

Legg, T.D., J.J. Fletcher, and K.W. Easter. 1989. Nitrogen budgets and economic efficiency: A case study of southeastern Minnesota. J. Prod. Agric. 2:110–116.

Miller, P.L., and A.F. MacKenzie. 1978. Effects of manures, ammonium nitrate, and S-coated urea on yield and uptake of N by corn and on subsequent inorganic N levels in soils in southern Quebec. Can. J. Soil Sci. 58:153–158.

Olsen, R.J., R.F. Hensler, O.J. Attoe, S.A. Witzel, and L.A. Peterson. 1970. Fertilizer nitrogen and crop rotation in relation to movement of nitrate nitrogen through soil profiles. Soil Sci. Soc. Am. Proc. 34:448–452.

Russelle, M.P., E.J. Deibert, R.D. Hauck, and R.A. Olson. 1981. Effects of water and nitrogen management on yield and ^{15}N-depleted fertilizer use efficiency of irrigated corn. Soil Sci. Soc. Am. J. 43:553–558.

SAS Institute. 1987. SAS/STAT guide to personal computers. Version 6 ed. SAS Inst., Cary, NC.

Schmid, A.R., A.C. Caldwell, and R.A. Briggs. 1959. Effect of various meadow crops, soybeans, and grain on the crops which follow. Agron. J. 51:160–162.

Shrader, W.D., W.A. Fuller, and F.B. Cady. 1966. Estimate of a common N response function for corn (*Zea mays*) in different crop rotations. Agron. J. 58:397–401.

Sutton, A.C., D.W. Nelson, and D.D. Jones. 1985. Utilization of animal manure as fertilizer. *In* Midwest Planning Service Publ. 18. Midwest Planning Service, Ames, IA.

Voss, R.D., and W.D. Shrader. 1979. Crop rotations: Effects on yields and response to nitrogen. Iowa State Univ. Coop. Ext. Service PM-9055.

Voss, R.D., and W.D. Shrader. 1984. Rotation effects and legume sources of nitrogen for corn. p. 61–68. *In* Organic farming: Current technology and its role in sustainable agriculture. ASA, CSSA, and SSSA, Madison, WI.

Weisberg, S. 1985. Applied linear regression. p. 179–183. John Wiley & Sons, New York.

Weisberg, S., and R.D. Cook. 1990. Linear and nonlinear regression methods. p. 163–199. *In* D. Berry (ed.) Statistical methodology in the pharmaceutical sciences. Marcel Dekker, New York.